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Nanoimprint TiO_2 Slot Layer for Hybrid EO polymer/TiO_2 Vertical Slot Waveguide Modulators

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Abstract

We have presented a new original soft process to fabricate slot waveguide modulators. In this work we have imprinted successfully a 100 nm-thick TiO_2 pattern layer on sol-gel silca cladding layer, which is coated on the line gratings arrays in the Si mold, widths up to 1μm, and 700nm depth. This fabrication process also enables the control of optical properties of TiO_2 pattern especially for its high refractive index and its lower optical propagation loss, in order to use in EO polymer/TiO_2 vertical slot waveguide modulators and biophotonic sensors.

1. Introduction

Most of optical sensors are based on the detection of refractive index changes during the interaction of the analytes and the immobilized molecules which provide the selectivity of the sensor system [1]. Thermal embossing or nanoimprint lithography for sputtered oxide materials attracts attention of researchers, because of the inherent advantages for direct nanostructure and micro pattern of functional films without additional steps of dry etching, and which is assisted by lithography with photoresist materials. [2-3]. Titanium dioxide (TiO_2) is the material chosen for the hybrid slot waveguide modulator devices[2], for reasons: 1) high transparency to the telecommunications band, and provides low propagation loss <1 dB/cm at 1550 nm, 2) the refractive index of TiO_2 that is lower than that of Si, but sufficiently greater than that of the Electro-optic (EO) polymer, which realizes higher optical mode confinement in the EO polymer, 3) the electrical resistivity for higher poling efficiency of the EO polymer and high speed optical modulation, and 4) the dielectric constant critical for low driving voltage in the hybrid EO polymer modulators. The electrical resistivity of TiO_2 is several orders smaller than that of the EO polymer; the dielectric constant of TiO_2 (> 30) is greater than that of the EO polymer (~ 2). Such a great contrast can induce DC field strengthened in the slot waveguide modulator. Various deposition techniques have been developed to deposit TiO_2 thin films, including evaporation, RF sputtering [3], CVD and also, the MOCVD method which is known to be one of the heaviest and most powerful technical suitable for stoichiometric microstructure for thin film of TiO_2. On the other hand, the ability to control the wettability of a solid surface and their surface energy is extremely important and useful in a range of technological applications. Other methods exist to get micro/nanopatterns of TiO_2 thin films, and has been fully investigated. In particular, microcontact printing (μCP) [3], which is a very convenient, and shows that the hydrophobic

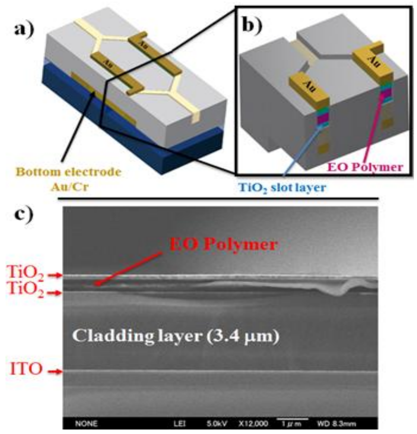

Fig. 1 Schematic of the EO polymer/TiO_2 multilayer slot waveguide modulator. (a) Bird's eye view. (b) Cross-sectional view. (c) SEM cross section view of the EO device.

units with dimensions of the order of microns can be formed on hydrophilic surfaces, without involving photolithographic type procedures. In conventional optical waveguide devices, EO active layer was sandwiched between high-index and TiO_2 slot layers (e.g., thickness of 0.1 μm) on a sol–gel silica cladding (TiO_2/EO polymer/TiO_2/sol–gel silica), and the mode confinement for the EO polymer in the EO polymer/TiO_2 vertical slot waveguide modulators (VSWM) was increased. Our original approach developed here is to present a new process named μCP, in order to fabricate high feature edge depth of micropatterns of TiO_2 thin films (high refractive index) used in the EO polymer/TiO_2 VSWM as shown in Fig. 1. Indeed our μCP approach is to use : 1) a sacrificial layer such as Gold (Au); 2) a silicon mold and solid stamp with line gratings patterns; 3) a receptive substrate based on sol-gel silica used as CL for EO device (as shown in Fig. 1-c). Only suitable thermal treatments are applied to functionalize materials and enables the adhesion and cohesion of TiO_2 during the patterning process (see Fig. 2 and Fig. 3). In addition, our μCP process avoids: i) oxygen plasma treatment that used by Uhrich et al. for μCP [4]; ii) high-pressure; iii) high-temperature annealing (<150°C). Furthermore, the Si mold and stamp can be cleaned and reused for several processes without degradation and contamination of the TiO_2 patterns layer. In this work, we demonstrated, the possibility to transfer a sputtered TiO_2 (high refractive index) by μCP, the optical constants are characterized by ellipsometry which reveals very low absorption and an high index of refraction and finally we assessed the success of this method at different micro-patterns, with different widths up to 1μm with the depths from 700nm to 1.2μm that could be used for EO device.

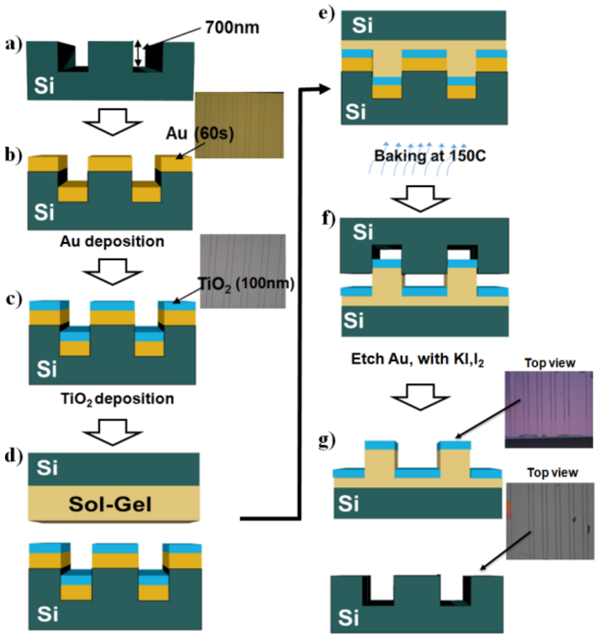

Fig. 2 Schematic of principle and patterning of μCP. The transfer process was performed from a) to g). The optical microscope images of the top view of patterns were shown in b), c) and g).

2. Results and discussion

The Fig. 2 shows the general flow of the μCP method. A Si master mold is made by etching the desired patterns: (line gratings), each with depth of 1μm. The line gratings are well matched to EO polymer/TiO_2 VSWM and biosensors application [1] (see Fig. 2a). A gold sacrificial layer (Au) was deposited by sputtering on the line gratings matching to Si master mold, (see Fig. 2b), afterward, TiO_2 was sputtered on Au receptive substrate, at the same time we deposit a thick sol-gel silica CL by spin coating on a very flat Si solid stamp substrate (see Fig. 2d). After that, the Si solid stamp and the TiO_2 film are brought into conformal contact with the mold and a soft baking at 150°C is applied (see Fig. 2e). Van der Waals interactions are taking effects, which are amplified by the thermal annealing process. Consequently, both sol-gel silica and TiO_2, were crystallize, therefore refractive index of TiO_2 will change to higher up to 2.32 at 1550nm and 2.42 at 589 nm, depending to crystallographic orientation [4]. Consecutively, an Au sacrificial layer was etched by (KI, I_2), and Si solid stamp was slow peeling (<10 cm/s) as shown Fig. 2f. Only TiO_2 patterns are remaining on the Si solid stamp, therefore the sol-gel silica CL gratings patterns are also detached and built with TiO_2 (see Fig. 2g). As a reference, all line gratings patterns were shown in Fig. 2 by microscopic image beside each step process. We applied the transfer technique for the vertical TiO_2 slot waveguide as shown in Fig. 1 with considering : i) the transformation ii) the patterning ii) the baking (crystallization) and iii) the transfer layer both (TiO_2 and silica sol-gel). The Fig. 3 showed imprinted line gratings arrays, with different widths (1.2, 1.3, 3.2, 5 and 10μm), and depth of 700nm and 1.2μm as shown in Fig. 3a, b, c and d. In this process, We found that about 85% of a total patterns area of 5 cm^2 is imprinted, without visible defects. However, we also observed that the annealing process at 150°C can sufficiently stabilize the imprinted feature and offer a continuous and dense TiO_2 patterning for each width of the line gratings (1 to 10 μm) as shown in Fig. 3. Furthermore, its top surface is smooth with roughness (root mean square) of at most 10 nm, it maintained the same thick (500 nm) of the EO polymer in EO polymer/TiO_2 VSWM and EO device. Finally, a EO coefficient of 190 pm/V was achieved for a thinner EO polymer (380 nm) sandwiched between two interfacial slot TiO_2 layers on the sol-gel CL as shown in Fig. 1, which reveals a better poling of the EO polymer film. As a next step, we will use our method to fabricate EO polymer/TiO_2 VSWM, in order to optimize and asses the efficiency of our approach for the EO device.

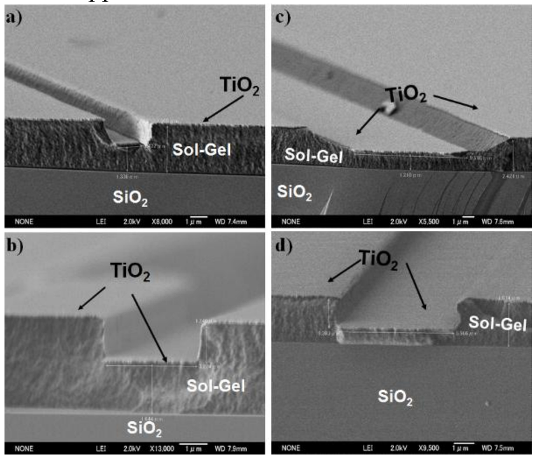

Fig. 3 the scanning electron microscope image of the cross-section of the sol-gel silica/TiO_2 line gratings for VSWM.

3. Conclusions

We conclude that μCP is effective and simple method to pattern each layer of sol-gel silica and TiO_2, with controlling its optical proprieties with maintaining it high refractive index and lower optical propagation loss for TiO_2, especially when TiO_2 slot layer is buried in EO waveguide device. We have pattern successfully a 100 nm-thick sputtered TiO_2 layer on sol-gel silica CL coated on line gratings Si mold. Finally, the TiO_2 patterns were transferred to sol-gel silica CL in the EO device. Thus this μCP method would be useful in the field of optical and photonic applications such as optical waveguide modulators and bio-chemical sensing applications based on fluorescent materials in the visible wavelength range.

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